AMENDMENTS TO THE CLAIMS

The following listing of claims replaces all prior versions of claims in the application.

1. (Original): A method for designing industrial products, characterized in that a shape of an industrial product is designed by using a three-dimensional curve (referred to as a three-dimensional clothoid curve) in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable.

2. (Original): The design method for industrial products according to claim 1, characterized in that

the industrial product is a machine including a mechanism in which a mechanical element having a mass moves and

a trajectory of motion of the mechanical element is designed by using the three-dimensional curve (referred to as the three-dimensional clothoid curve).

3. (Original): The design method for industrial products according to claim 2, characterized in that

the machine is a screw device including a mechanism in which a ball as the mechanical element moves,

the screw device comprises a screw shaft having an outer surface on which a spiral rolling element rolling groove is formed, a nut having an inner surface on which a load rolling element rolling groove is formed so as to be opposed to the rolling element rolling groove and a regression path is formed to connect a one end and the other end of the load rolling element rolling groove, and a plurality of rolling elements disposed between the rolling element rolling groove of the screw shaft and the load rolling element rolling groove of the nut and disposed in the regression path, and

the regression path of the screw device is designed by using the three-dimensional curve (referred to as the three-dimensional clothoid curve).

4. (Currently amended): The design method for industrial products according to ~~any one of claims 1 to 3~~ claim 1, characterized in that the three-dimensional clothoid curve is defined by the following expressions.

[Numeral 126]

$$P = P_0 + \int_0^s u\,ds = P_0 + h\int_0^S u\,dS, \quad 0 \le s \le h, \quad 0 \le S = \frac{s}{h} \le 1 \tag{1}$$

$$u = E^{k\beta}E^{j\alpha}(i) = \begin{bmatrix} \cos\beta & \sin\beta & 0 \\ \sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\alpha & 0 & \sin\alpha \\ 0 & 1 & 0 \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix} \begin{Bmatrix} 1 \\ 0 \\ 0 \end{Bmatrix} = \begin{Bmatrix} \cos\beta\cos\alpha \\ \sin\beta\cos\alpha \\ -\sin\alpha \end{Bmatrix} \tag{2}$$

$$\alpha = a_0 + a_1 S + a_2 S^2 \tag{3}$$

$$\beta = b_0 + b_1 S + b_2 S^2 \tag{4},$$

wherein

[Numeral 127]

$$P = \begin{Bmatrix} x \\ y \\ z \end{Bmatrix}, \quad P_0 = \begin{Bmatrix} x_0 \\ y_0 \\ z_0 \end{Bmatrix} \tag{5}$$

shows a positional vector at each point on the three-dimensional clothoid curve and its initial value, respectively.

Assume that the length of a curve from a starting point is s and its whole length (a length from the starting point to an end point) is h. A value produced by dividing s by h is expressed as S. S is a dimensionless value, which is called a curve length variable.

i, j and k are unit vectors in the x-axis, y-axis and z-axis directions, respectively.

u is a unit vector showing a tangential direction of a curve at a point P, which is given by Expression (2). $E^{k\beta}$ and $E^{j\alpha}$ are rotation matrices and represent an angular rotation of angle β about

the k-axis and an angular rotation of angle α about the j-axis, respectively. The former is referred to as a yaw rotation, while the latter is referred to as a pitch rotation. Expression (2) means that the unit vector in the i-axis direction is rotated by an angle α about the j-axis, before being rotated by an angle β about the k-axis, thus producing a tangent vector u. a_0, a_1, a_2, b_0, b_1 and b_2 are constants.

5. (Original): The design method for industrial products according to claim 4, characterized in that a plurality of spatial points are specified in a three-dimensional coordinate and these spatial points are interpolated by using the three-dimensional clothoid curve, whereby the shape of the industrial product is designed.

6. (Original): The design method for industrial products according to claim 5, characterized in that seven parameters a_0, a_1, a_2, b_0, b_1, b_2 and h of the three-dimensional clothoid segments are calculated so that, between a one three-dimensional clothoid segment (a unit curve consisting of a group of curves produced on the interpolation) and the next three-dimensional clothoid segment (a unit curve consisting of a group of curves produced on the interpolation), positions, tangential directions, normal directions, and curvatures of both the one and next three-dimensional clothoid segments are made continuous to each other, respectively, at the plurality of spatial points.

7. (Original): The design method for industrial products according to claim 6, characterized in that

the seven parameters a_0, a_1, a_2, b_0, b_1, b_2 and h of the three-dimensional clothoid segments are calculated by making the number of conditional expressions produced by mutual addition to be made between conditional expressions concerning the tangential directions, the normal directions and the curvatures at both the starting point and the end point and further conditional expressions allowing the positions, the tangential directions, the normal directions, and the curvatures of both the one and next three-dimensional clothoid segments to be made continuous to each other, respectively, at the plurality of spatial points agree with the unknowns of the seven parameters a_0,

a_1, a_2, b_0, b_1, b_2 and h of the three-dimensional clothoid segments, whereby the conditional expressions is made agree with the unknowns in terms of number thereof, by specifying the tangential directions, the normal directions and the curvatures at the stating point and the and point among the plurality of spatial points and additionally inserting objective points being interpolated between the spatial points which have been specified in advance.

8. (Currently amended): An industrial product designed by using the design method for industrial products according to ~~any one of claims 1 to 7~~ claim 1.

9. (Original): A program, which is for designing a shape of an industrial product, enabling a computer to operate as means to design the shape of the industrial product by using a three-dimensional curve (referred to as a three-dimensional clothoid curve) in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable.

10. (Original): A computer-readable recording medium, which is for designing a shape of an industrial product, recording thereon a program enabling a computer to operate as means to design the shape of the industrial product by using a three-dimensional curve (referred to as a three-dimensional clothoid curve) in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable.

11. (Original): A numerical control method expressing a trajectory of a machine tool or a contour shape of a workpiece by using a three-dimensional curve (referred to as a three-dimensional clothoid curve) in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable and controlling motion of the machine tool based on the three-dimensional curve.

12. (Original): The numerical control method according to claim 11, wherein the three-dimensional clothoid is defined by the following expressions.

[Numeral 128]

$$P = P_0 + \int_0^s u ds = P_0 + h \int_0^S u dS, \quad 0 \le s \le h, \quad 0 \le S = \frac{s}{h} \le 1 \qquad (1)$$

$$u = E^{k\beta} E^{j\alpha}(i) = \begin{bmatrix} \cos\beta & -\sin\beta & 0 \\ \sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\alpha & 0 & \sin\alpha \\ 0 & 1 & 0 \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix} \begin{Bmatrix} 1 \\ 0 \\ 0 \end{Bmatrix} = \begin{Bmatrix} \cos\beta\cos\alpha \\ \sin\beta\cos\alpha \\ -\sin\alpha \end{Bmatrix} \qquad (2)$$

$$\alpha = a_0 + a_1 S + a_2 S^2 \qquad (3)$$

$$\beta = b_0 + b_1 S + b_2 S^2 \qquad (4),$$

wherein

[Numeral 129]

$$P = \begin{Bmatrix} x \\ y \\ z \end{Bmatrix}, \quad P_0 = \begin{Bmatrix} x_0 \\ y_0 \\ z_0 \end{Bmatrix} \qquad (5)$$

shows a positional vector at each point on the three-dimensional clothoid curve and its initial value, respectively.

Assume that the length of a curve from a starting point is s and its whole length (a length from the starting point to an end point) is h. A value produced by dividing s by h is expressed as S. S is a dimensionless value, which is called a curve length variable.

i, j and k are unit vectors in the x-axis, y-axis and z-axis directions, respectively.

u is a unit vector showing a tangential direction of a curve at a point P, which is given by Expression (2). $E^{k\beta}$ and $E^{j\alpha}$ are rotation matrices and represent an angular rotation of angle β about the k-axis and an angular rotation of angle α about the j-axis, respectively. The former is referred

to as a yaw rotation, while the latter is referred to as a pitch rotation. Expression (2) means that the unit vector in the i-axis direction is rotated by an angle α about the j-axis, before being rotated by an angle β about the k-axis, thus producing a tangent vector u. In this Expression, a_0, a_1, a_2, b_0, b_1 and b_2 are constants.

13. (Original): A numerical control device expressing a trajectory of a machine tool or a contour shape of a workpiece by using a three-dimensional curve (referred to as a three-dimensional clothoid curve) in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable and controlling motion of the machine tool based on the three-dimensional curve.

14. (Original): A program, which is for numerically controlling motion of a machine tool, enabling a computer to operate as means to express a trajectory of the machine tool or a contour shape of a workpiece by using a three-dimensional curve (referred to as a three-dimensional clothoid curve) in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable.

15. (Original): A computer-readable recoding medium, which is for numerically controlling motion of a machine tool, recording thereon either a program enabling a computer to operate as means to express a trajectory of the machine tool or a contour shape of a workpiece by using a three-dimensional curve (referred to as a three-dimensional clothoid curve) in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable, or results computed based on the program.

16. (Original): A numerical control method comprising steps of interpolating points of a row of points arbitrarily given in a three-dimensional coordinate by using a three-dimensional curve (referred to as three-dimensional clothoid segments) in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length

variable and controlling motion of a machine tool based on the three-dimensional clothoid segments.

17. (Original): A numerical control method comprising steps of mutually connecting a plurality of three-dimensional clothoid curves (each of which is referred to as three-dimensional clothoid segments) in each of which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable and controlling motion of a machine tool based on the plural three-dimensional clothoid segments.

18. (Currently amended): The numerical control method according to claim 16 [[or 17]], wherein the three-dimensional clothoid curve is defined by the following expressions.

[Numeral 130]

$$P = P_0 + \int_0^s u\,ds = P_0 + h\int_0^S u\,dS, \quad 0 \le s \le h, \quad 0 \le S = \frac{s}{h} \le 1 \tag{1}$$

$$u = E^{k\beta}E^{j\alpha}(i) = \begin{bmatrix} \cos\beta & -\sin\beta & 0 \\ \sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\alpha & 0 & \sin\alpha \\ 0 & 1 & 0 \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix} \begin{Bmatrix} 1 \\ 0 \\ 0 \end{Bmatrix} = \begin{Bmatrix} \cos\beta\cos\alpha \\ \sin\beta\cos\alpha \\ -\sin\alpha \end{Bmatrix} \tag{2}$$

$$\alpha = a_0 + a_1 S + a_2 S^2 \tag{3}$$

$$\beta = b_0 + b_1 S + b_2 S^2 \tag{4}$$

wherein,

[Numeral 131]

$$P = \begin{Bmatrix} x \\ y \\ z \end{Bmatrix}, \quad P_0 = \begin{Bmatrix} x_0 \\ y_0 \\ z_0 \end{Bmatrix} \tag{5}$$

shows a positional vector at each point on the three-dimensional clothoid curve and its initial value, respectively.

Assume that the length of a curve from a starting point is s and its whole length (a length from the starting point to an end point) is h. A value produced by dividing s by h is expressed as S. S is a dimensionless value, which is called a curve length variable.

i, j and k are unit vectors in the x-axis, y-axis and z-axis directions, respectively.

u is a unit vector showing a tangential direction of a curve at a point P, which is given by Expression (2). $E^{k\beta}$ and $E^{j\alpha}$ are rotation matrices and represent an angular rotation of angle β about the k-axis and an angular rotation of angle α about the j-axis, respectively. The former is referred to as a yaw rotation, while the latter is referred to as a pitch rotation. Expression (2) means that the unit vector in the i-axis direction is rotated by an angle α about the j-axis, before being rotated by an angle β about the k-axis, thus producing a tangent vector u. a_0, a_1, a_2, b_0, b_1 and b_2 are constants.

19. (Original): The numerical control method according to claim 18, characterized in that the seven parameters a_0, a_1, a_2, b_0, b_1, b_2 and h are calculated in such a manner that, at a connecting point between, of the plural three-dimensional clothoid segments, a single three-dimensional clothoid segment and the next three-dimensional clothoid segment thereto, positions and tangential directions (and in some cases, curvatures) of both three-dimensional clothoid segments are continuous, respectively.

20. (Original): A numerical control device interpolating points of a row of points arbitrarily given in a three-dimensional coordinate by using a three-dimensional curve in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable and controlling motion of a machine tool based on the three-dimensional clothoid segments.

21. (Original): A program, which is for numerically controlling motion of a machine tool, enabling a computer to operate as means to interpolate points of a row of points arbitrarily given in a three-dimensional coordinate by using a three-dimensional curve in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable and controlling the motion of the machine tool based on the three-dimensional clothoid segments.

22. (Original): A computer-readable recording medium, which is for numerically controlling motion of a machine tool, recording either a program enabling a computer as means for interpolating points of a row of points arbitrarily given in a three-dimensional coordinate by using a three-dimensional curve in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable, or results calculated on the program.

23. (Original): A numerical control method comprising steps of

expressing a trajectory of a machine tool or a contour shape of a workpiece by using a three-dimensional curve (referred to as a three-dimensional clothoid curve) in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable,

specifying motion of the machine tool to be moved along the three-dimensional curve, and

calculating a moved position of the machine tool at unit-time intervals according to the specified motion,

wherein the motion is defined as positional information changing as a function of time.

24. (Original): The numerical control method according to claim 23, wherein the three-dimensional clothoid curve is defined by the following expressions.

[Numeral 132]

$$P = P_0 + \int_0^s u\,ds = P_0 + h\int_0^S u\,dS, \quad 0 \le s \le h, \quad 0 \le S = \frac{s}{h} \le 1$$

(1)

$$u = E^{k\beta}E^{j\alpha}(i) = \begin{bmatrix} \cos\beta & -\sin\beta & 0 \\ \sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} \cos\alpha & 0 & \sin\alpha \\ 0 & 1 & 0 \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix}\begin{Bmatrix} 1 \\ 0 \\ 0 \end{Bmatrix} = \begin{Bmatrix} \cos\beta\cos\alpha \\ \sin\beta\cos\alpha \\ -\sin\alpha \end{Bmatrix}$$

(2)

$$\alpha = a_0 + a_1 S + a_2 S^2 \qquad (3)$$

$$\beta = b_0 + b_1 S + b_2 S^2 \qquad (4)$$

wherein,
[Numeral 133]

$$P = \begin{Bmatrix} x \\ y \\ z \end{Bmatrix}, \quad P_0 = \begin{Bmatrix} x_0 \\ y_0 \\ z_0 \end{Bmatrix} \qquad (5)$$

shows a positional vector at each point on the three-dimensional clothoid curve and its initial value, respectively.

Assume that the length of a curve from a starting point is s and its whole length (a length from the starting point to an end point) is h. A value produced by dividing s by h is expressed as S. S is a dimensionless value, which is called a curve length variable.

i, j and k are unit vectors in the x-axis, y-axis and z-axis directions, respectively.

u is a unit vector showing a tangential direction of a curve at a point P, which is given by Expression (2). $Ek\beta$ and $Ej\alpha$ are rotation matrices and represent an angular rotation of angle β about the k-axis and an angular rotation of angle α about the j-axis, respectively. The former is referred to as a yaw rotation, while the latter is referred to as a pitch rotation. Expression (2) means that the unit vector in the i-axis direction is rotated by an angle α about the j-axis, before being rotated by an angle β about the k-axis, thus producing a tangent vector u. a_0, a_1, a_2, b_0, b_1 and b_2 are constants.

25. (Original): A numerical control device which is configured to

express a trajectory of a machine tool or a contour shape of a workpiece by using a three-dimensional curve (referred to as a three-dimensional clothoid curve) in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable,

specify motion of the machine tool to be moved along the three-dimensional curve, and

calculate a moved position of the machine tool at unit-time intervals according to the specified motion,

wherein the motion is defined as positional information changing as a function of time.

26. (Original): A program, which is for numerically controlling motion of a machine tool, enabling a computer to operate as

means for expressing a trajectory of a machine tool or a contour shape of a workpiece by using a three-dimensional curve (referred to as a three-dimensional clothoid curve) in which each of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable,

means for specifying motion of the machine tool to be moved along the three-dimensional curve, and

means for calculating a moved position of the machine tool at unit-time intervals according to the specified motion,

wherein the motion is defined as positional information changing as a function of time.

27. (Original): A computer-readable recording medium, which is for numerically controlling motion of a machine tool, recording thereon a program enabling a computer to operate as

means for expressing a trajectory of a machine tool or a contour shape of a workpiece by using a three-dimensional curve (referred to as a three-dimensional clothoid curve) in which each

of a pitch angle and a yaw angle in a tangential direction is given by a quadratic expression of a curve length or a curve length variable,

means for specifying motion of the machine tool to be moved along the three-dimensional curve, and

means for calculating a moved position of the machine tool at unit-time intervals according to the specified motion,

wherein the motion is defined as positional information changing as a function of time.

28. (New): The numerical control method according to claim 17, wherein the three-dimensional clothoid curve is defined by the following expressions.

[Numeral 130]

$$P = P_0 + \int_0^s u\,ds = P_0 + h\int_0^S u\,dS, \quad 0 \le s \le h, \quad 0 \le S = \frac{s}{h} \le 1 \tag{1}$$

$$u = E^{k\beta}E^{j\alpha}(i) = \begin{bmatrix} \cos\beta & -\sin\beta & 0 \\ \sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\alpha & 0 & \sin\alpha \\ 0 & 1 & 0 \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix} \begin{Bmatrix} 1 \\ 0 \\ 0 \end{Bmatrix} = \begin{Bmatrix} \cos\beta\cos\alpha \\ \sin\beta\cos\alpha \\ -\sin\alpha \end{Bmatrix} \tag{2}$$

$$\alpha = a_0 + a_1 S + a_2 S^2 \tag{3}$$

$$\beta = b_0 + b_1 S + b_2 S^2 \tag{4}$$

wherein,

[Numeral 131]

$$P = \begin{Bmatrix} x \\ y \\ z \end{Bmatrix}, \quad P_0 = \begin{Bmatrix} x_0 \\ y_0 \\ z_0 \end{Bmatrix} \tag{5}$$

shows a positional vector at each point on the three-dimensional clothoid curve and its initial value, respectively.

Assume that the length of a curve from a starting point is s and its whole length (a length from the starting point to an end point) is h. A value produced by dividing s by h is expressed as S. S is a dimensionless value, which is called a curve length variable.

i, j and k are unit vectors in the x-axis, y-axis and z-axis directions, respectively.

u is a unit vector showing a tangential direction of a curve at a point P, which is given by Expression (2). $E^{k\beta}$ and $E^{j\alpha}$ are rotation matrices and represent an angular rotation of angle β about the k-axis and an angular rotation of angle α about the j-axis, respectively. The former is referred to as a yaw rotation, while the latter is referred to as a pitch rotation. Expression (2) means that the unit vector in the i-axis direction is rotated by an angle α about the j-axis, before being rotated by an angle β about the k-axis, thus producing a tangent vector u. a_0, a_1, a_2, b_0, b_1 and b_2 are constants.